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ON THE LENGTH OF THE TIME OF CONTACT IN THE CASE OF A QUICK TAP ON A TELEGRAPH KEY.

BY B. OSGOOD PEIRCE.

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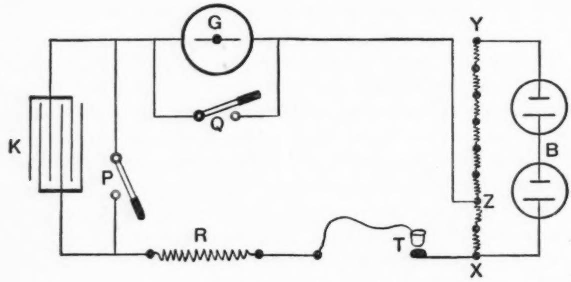
In the use of a sensitive mirror, needle, ballistic galvanometer, in cases where a moving-coil galvanometer is objectionable, and the familiar sliding-coil-on-a-long-magnet arresting apparatus unsuitable, it is sometimes desirable to control the needle by currents of short duration, sent through either a coil of the galvanometer or an auxiliary coil, in one direction or the other, by aid of a pair of reversing keys. The current through the controlling circuit during a comparatively long depression of the key must be strong enough to check quickly a large swing of the needle, and yet the operator must be able to bring the needle practically to rest when its whole range, as measured by the indication on its scale, is only a small fraction of a millimeter. To do this quickly and surely requires some skill in making short key contacts, as every person who has tried it knows, and different observers find it well to use different strengths of current in the controlling circuit. In order to be able to plan wisely some apparatus, I have lately found it desirable to learn about how short a contact the average observer can make, either with a telegraph key or with a thimble on the finger, and, through the kindness of a number of my colleagues and friends, I have been able to get the results given below.

The measurements were made according to a well-known principle, by determining either the fractional part of the whole charge of a given loaded condenser lost during the key contact by short circuit through a given resistance, or the fractional part of a full charge gained by an originally empty condenser, through a given resistance, when a fixed electromotive force was applied during the time of closure of the key. It is well known that with proper choice of the apparatus this proce-

dure is susceptible of great accuracy, and that it furnishes satisfactory means of determining the velocity of a rifle ball, or the rate of propagation of an elastic wave in a bar of metal, or the time of contact of a hammer and an anvil. Some time ago I had to measure with some care an interval of time of about one five thousandth of a second, and to test the apparatus, used a good number of different combinations of condensers and resistances in the circuit, with the result that the determinations agreed within the very small uncertainty caused by the fact that it was difficult to be sure that the suspended system of the ballistic galvanometer used was originally exactly at rest.

The arrangement of the apparatus for measuring the time of closure of the key is shown schemetically in the subjoined diagram. K represents a divided mica condenser of about 28.8 microfarads capacity;



G, a ballistic mirror galvanometer; R, a large known resistance; T is the point of contact of the key with its base, or of the thimble with its block; P and Q are keys mounted on a large block of parrafine for discharging the condenser and short-circuiting the galvanometer after every throw. In order to make the potential difference across the open key at all times small, the ends of the condenser circuit were attached to two points (X, Z) in the closed high resistance current of one or two cells, so chosen as to make the galvanometer throw, corresponding to a complete loading of the condenser, a convenient number of centimeters; the final adjustment of this throw to a predetermined value was made by moving the scale (along a track made for the purpose) away from or nearer to the galvanometer mirror.

It is evident that if k is the capacity in farads of the condenser, r the whole resistance in ohms of the condenser branch circuit, and $(u + v)$, of which v is the resistance of the plain conductor between X and Z, in the resistance of the battery circuit, then, when P and Q

are open, the charge in coulombs in the originally empty condenser, t seconds after the key, T, is closed, is

$$Q_t = \frac{e\,k\,v}{u+v}\left(1 - e^{\frac{-(u+v)t}{k(uv+ur+vr)}}\right),$$

and $$Q_\infty = \frac{e\,v\,k}{u+v},$$

so that $$t = \frac{k\,(u\,v + u\,r + v\,r)}{u+v} \cdot \log_e\left(\frac{Q_\infty}{Q_\infty - Q_t}\right).$$

The values of the natural logarithms which enter into this equation for several values of the ratio of Q_t to Q_∞ are as follows:

Q_t/Q_∞.	$\log_e[(Q_\infty - Q_t)/Q_\infty]$.	Q_t/Q_∞.	$\log_e[(Q_\infty - Q_t)/Q_\infty]$.
0.05	0.05130	0.40	0.51083
0.10	0.10537	0.45	0.59784
0.15	0.16252	0.50	0.69315
0.20	0.22315	0.55	0.79851
0.25	0.28769	0.60	0.91629
0.30	0.35668	0.65	1.04983
0.35	0.43079	0.70	1.20398

For the long scale distances actually used, the throw of the galvanometer caused by a discharge of electricity through its coil was, as measured on the scale of the instrument, sensibly proportional, up to a reading of say 25 centimeters, to the quantity of the discharge. The galvanometer and the resistances u and v were usually so adjusted that a complete load (Q_∞) of the condenser, when sent through the coil, caused a throw of exactly 20 centimeters. After k, u, v, and r had been fixed, the coefficient of the logarithm remained constant; if, for example, its mean was 0.05, a throw of 50 millimeters would be caused by closing the key for about 0.0144 seconds.

In order to make sure that the apparatus had been properly set up, I made use of a body falling from rest through a measured space to close the gap T for a short interval of calculable length. A heavy weight sliding on a stout vertical brass rod carried with it an insulated frame which held securely a printer's lead, which formed one terminal of the gap T. Projecting about a millimeter from a hole in the vertical rod, near the lower end, was a piece of sharpened drill rod which formed

the other terminal of T, and ploughed a clean furrow in the lead as the weight, in falling, carried the lead by. In this way sure contact across the gap could be made for a time interval, which could be varied between limits, the length of which could be computed with some accuracy. The agreement between the results obtained by this device and those calculated from the electrical constants was always so close as to lie within the uncertainty of the zero of the galvanometer.

Using the apparatus just described, a large number of trials were made by about twenty different persons to determine how short a

TABLE I.

Observer.	Average time of contact of key as obtained from all the trials.	Average time of contact of key as obtained from the shorter half of the observations.	Observer.	Average time of contact of key as obtained from all the trials.	Average time of contact of key as obtained from the shorter half of the observations.
B	0.0329	0.0223	L	0.0203	0.0130
C	0.0278	0.0185	M	0.0303	0.0257
D	0.0368	0.0292	N	0.0166	0.0095
E	0.0223	0.0141	O	0.0175	0.0112
F	0 0383	0.0305	P	0.0107	0.0050
G	0.0606	0.0525	Q	0.0277	0.0112
H	0.0239	0.0166	R	0.0416	0.0362
I	0.0871	0.0788	S	0.0318	0.0284
J	0.0210	0.0147	T	0.0350	0.0280
K	0.0239	0.0178			

contact each could surely make with a telegraph key or with a thimble on a plate. If a telegraph key is furnished with a very stiff spring it is possible for any one, after a little practice, to make short contacts, not more than a thousandth of a second long, by *striking* the key with the hand; the observations recorded below were all made with a key which had no spring, and which had to be lifted, after the contact, by hand. It generally appeared that in the course of a long series of trials a person made two or three contacts of abnormal length (sometimes five or ten times as long as the mean of the others), but it did not seem well to leave them out of account; I have, therefore, given

the average length of all the contacts, and also the average length of the half of the whole number which were shortest. I am indebted to Mr. John Coulson for help in making the observations.

The recorded averages are given in ten thousandths of a second, but of course the average of two long sets of trials made by the same person would not agree exactly. There is, however, in most cases, a striking agreement between observations made at different times by

TABLE II.

Observer.	Hand.	Average time of contact of thimble and plate as obtained from all the trials.	Average time of contact of thimble and plate as obtained from the shorter half of the observations.	Observer.	Hand.	Average time of contact of thimble and plate as obtained from all the trials.	Average time of contact of thimble and plate as obtained from the shorter half of the observations.
A	Right	0.0077	0.0037	J	Right	0.0110	0.0045
B	Right	0.0060	0.0028	J	Left	0.0136	0.0086
C	Right	0.0083	0.0046	K	Right	0.0170	0.0062
C	Left	0.0061	0.0037	L	Right	0.0139	0.0078
D	Right	0.0126	0.0066	M	Right	0.0246	0.0035
E	Right	0.0077	0.0035	N	Right	0.0082	0.0036
E	Left	0.0062	0.0038	O	Right	0.0032	0.0022
F	Right	0.0034	0.0027	P	Right	0.0037	0.0032
G	Right	0.0217	0.0077	P	Left	0.0110	0.0028
H	Right	0.0053	0.0032	T	Right	0.0064	0.0051
I	Right	0.0303	0.0083				

one observer, and except in the cases of two persons whose records at the beginning were not very good, practice did not shorten the time appreciably. In my own case the shortest average that I have been able to get differs from my longest by about one sixth part of the latter. The records of thimble contacts made by two persons were 0.0036 and 0.0083 seconds in November, and 0.0037 and 0.0083 seconds in January.

Table I shows results obtained with the telegraph key, and, though the range is large, it appears that, when the key must be lifted away

from its seat after the contact by the observer, *the average person can surely make a contact as short as a thirtieth of a second*, and some can always do better than this. Table II shows records of fair contacts obtained with a thimble and block. While *the lengths of the shorter contacts of the average person seem to be rather less* — when made in this manner — *than one two hundredth of a second*, three of the persons (F, O, P) who made trial of the apparatus could surely make contacts the average lengths of which were only about one three hundredth of a second.

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